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Water Use Efficiency of Soybean and its Yield Response to Evapotranspiration and Rainfall

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ABSTRACT

Water requirement of soybean varies with climatic conditions and length of the growing season. Moisture deficiency during vegetative stage of soybean development reduces the rate of plant growth and the yield of soybean is adversely affected by moisture stress during the pod-filling period. In this study, data for four stations Rahuri, Parbhani, Banswara and Bhopal for the years 1990 to 1993 have been analysed to understand the various characteristics of evapotranspiration of the soybean crop including its impact on yield. Change in ET/EP ratio with the crop growth has been critically examined and a generalised growth and ET/EP relationship has been evolved. The relationship is found to be exponential with significant correlation coefficient. An attempt has also been made to find the impact of rainfall on grain yield by regression analysis.

The results of the study indicate that the soybean crop uses maximum water during the vegetative stage. The ET/EP ratio gradually increases from sowing onwards, attaining a maximum during the flowering phase. During both, vegetative and maturity phase, the ET/EP ratio is considerably large and is nearly 75% of the atmospheric demand. The yield was found to be significantly correlated with the rainfall during vegetative phase indicating that rainfall during this phase plays a crucial role in the crop development and yield.

The efficiency of a field crop to use available water is governed largely by its variety, soil type and environmental conditions. Naturally the water use efficiency of soybean is found to vary from location to location but even at the same location for a specific variety, the efficiency changes with changes in weather conditions. When seed yield was correlated with ET during different phases as also during complete crop duration, significant correlation was obtained between yield and ET during vegetative phase only.

Introduction

The soyabean crop, compared to other important field crops, is not extensively distributed throughout the world. The seed has a protein rich value and hence, in recent years, it is increasingly being grown in many countries in varied environmental conditions. Soyabean is a thermo-sensitive crop and its growth rate and blooming date are often affected by temperature right from germination onwards. Emergence of soyabean is seldom observed at 20% soil moisture. At lower moisture levels, the small and medium sized seed gives more rapid emergence and greater root development than large seed. Water requirement of soyabean varies with climatic conditions, management practices and length of growing season. Yield of soyabean is adversely affected by moisture stress during the pod filling period and may result in 20-50 per cent reductions in the yield.

Runge and Odell (1960) found that the long flowering period enables the plant to escape or survive periods of drought stress and failure of early flowers to set pods due to water stress may be compensated by excellent pod set of late flowers if moisture is available. According to Thompson (1970) shortage of moisture during pod-filling stage reduces yield more than during the flowering stage. Therefore, if limited water is available for irrigation, application during the pod-filling stage proves most beneficial. Singh and Saxena (1969) reported that soyabean can withstand short periods of drought and tolerate short periods of waterlogged soils relatively better than corn.

Not much work seems to have been undertaken in India on agrometeorology of this important crop.

The present study aims at finding out agrometeorological characteristics of this crop. It is also proposed to find whether simple empirical models could be developed between soyabean yield and the climatic variations in different parts of India.

Materials and methods

The study pertains to four locations *viz.*, Banswara (23.5°N, 74.5°E), Bhopal (23.3°N, 77.4°E), Parbhani (19.3°N, 76.8°E), and Rahuri (19.4°N, 74.7°E), located mainly in the semi-arid tracks of India. Available data for soil types, variety used, mean seasonal rainfall, date of sowing/ harvesting etc. are given in Table 1. The meteorological data *viz.*, rainfall, temperature, humidity, evaporation etc. were recorded at observatories located close to the crop fields. The evapotranspiration (ET) was measured through gravimetric lysimeters located in the crop fields. The lysimeter consists of sensitive dormant type weighing machine of two tonne capacity, erected in the middle of the crop field on a reinforced concrete structure. A steel tank 1.3 x 1.3 x 0.9 m in size in which plants are grown is mounted on the platform of the machine such that its rim is in level with the surrounding soil surface. The evaporation (EP) values refer to those observed from class a open pan evaporimeter. From the daily data, weekly totals/means of these parameters from the date of sowing to maturity were computed.

Results and Discussions

Evapotranspiration

From the actual measurements it was observed that, the total consumptive use during the entire crop life period varied from 30.9 cm for a 99 days duration crop to 60.9 cm for a crop duration of 120 days. It may be pointed out that maximum water use estimates of 64-75 cm have been reported for soyabean in the arid zone. In the present study, the large range, however was observed at Banswara and not at other stations. Average ET for different phases at different locations has been worked out (Table 2). The most important feature emerging from the table is that, soyabean crop in Bhopal and Parbhani consumes more water during flowering and maturity stages as compared with the other two stations. During vegetative phase, Banswara is found to consume maximum water. The mean daily water use was found as 4.2 mm per day with a range from 3.1 mm to 5.1 mm per day when the data of all stations were clubbed together. These values appear reasonable though

Table 1. Soil and crop details

Station	Soil type	Field capacity	Crop variety and normal duration (days)	Date of sowing	Date of harvest	Crop duration (days)	Grain yield (kg ha^{1})		Total ET (mm)	Water use efficiency (kg ha^{-1} mm^{-1})
							Actual	Potential		
Nanswara	Medium black loam clay	38.0	Gaurav (104-106)	25.6.90	23.10.90	120	2257	2250	608.8	3.71
				15.7.91	22.10.91	99	2431	2250	308.6	7.88
Bhopal	Medium black clay	30.9	Punjab-1 (95-100)	22.7.92	23.10.92	93	2063	2100	446.6	4.62
				23.6.93	11.10.93	110	1809	2100	607.4	4.87
Parbhani	Medium dark brown clay	37.1	Monetta (85-90)	20.6.90	24.9.90	96	551	2150	426.2	1.29
				15.6.91	10.9.91	87	819	2150	362.5	2.26
				17.6.92	16.9.92	91	565	2150	413.2	1.37
Rahuri	Medium black clay	42.0	MACS-124 (95-100)	24.6.92	6.10.92	104	1923	3000	361.5	5.32
				28.6.93	13.10.93	107	2266	3000	451.0	5.02

Table 2. Mean Daily ET in mm

Location	Phases		
	Vegetative	Flowering	Maturity
Banswara	5.4	4.2	2.4
Bhopal	3.8	6.6	6.1
Parbhani	4.1	5.6	4.0
Rahuri	3.8	4.3	3.7
Mean	**4.4**	**5.2**	**3.8**

Whitt and Van Bavel (1955) reported a daily use of water of 7.6 mm which appear quite large for Indian conditions.

Evapotranspiration vs Evaporation

The evaporative power of the atmosphere can be adequately described by the evaporation from the open water surface. Extent to which this demand is met by an actively growing crop can be represented by the ratio of evapotranspiration to evaporation (ET / EP). Mean phase wise values of this ratio are given in Table 3. It is seen that, in the flowering phase the plant consumes water nearly equal to the atmospheric demand (i.e. EP). During both; vegetative phases and maturity phases the ET/EP ratio is considerably large and is nearly 75% of the atmospheric demand.

Table 3. Phase-wise variations in ET/EP ratio

Growth phase	Max	Min	Mean	S.D.
Vegetative	0.79	0.55	0.69	0.08
Flowering	1.88	0.32	1.09	0.43
Maturity	1.35	0.05	0.73	0.33
Mean	**1.11**	**0.37**	**0.75**	**0.19**

March of ET/EP ratio with the crop growth (in terms of per cent) for different stations is shown in Fig 1. It is seen that, the ratio in general rises till the flowering phase when nearly 60% of the life period of the crop is completed. The ET/EP values subsequently decline gradually. A generalized growth and ET/EP relationship is depicted in Fig. 2. As is obvious, the relationship is polynomial with coefficient of correlation r = 0.98 which was significant at 1% level. The

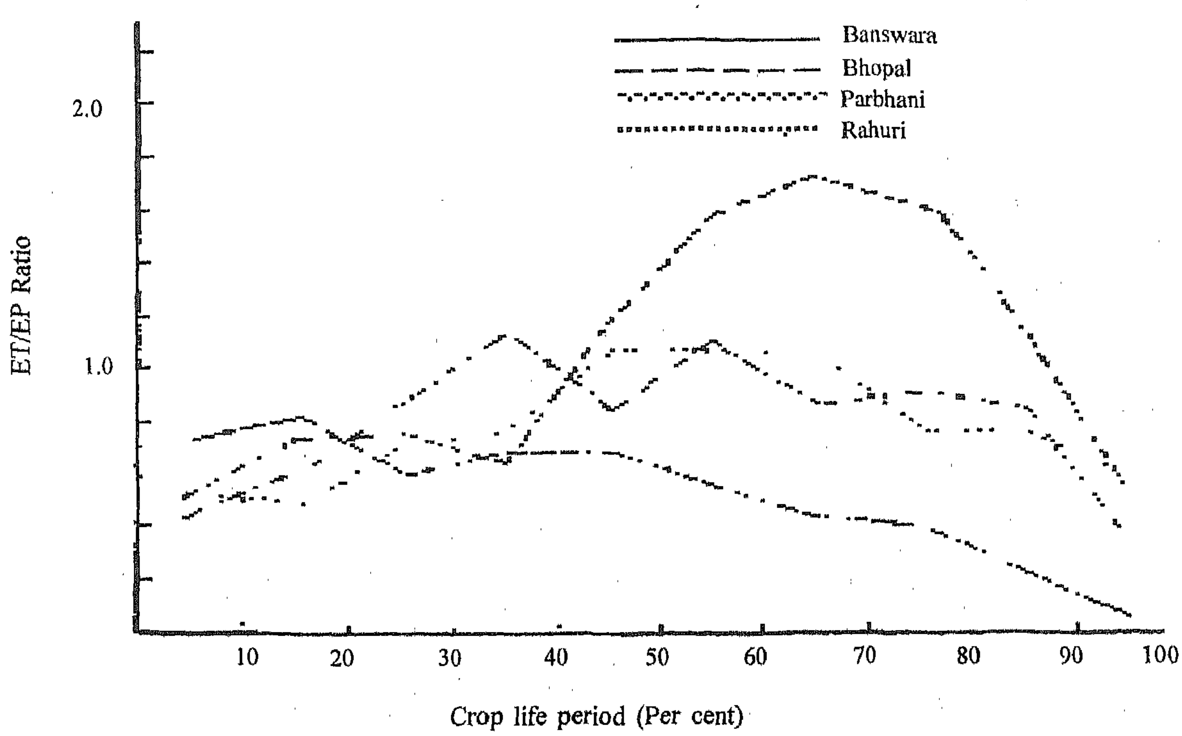

Fig. 1. March of ET/EP ratio with the crop growth

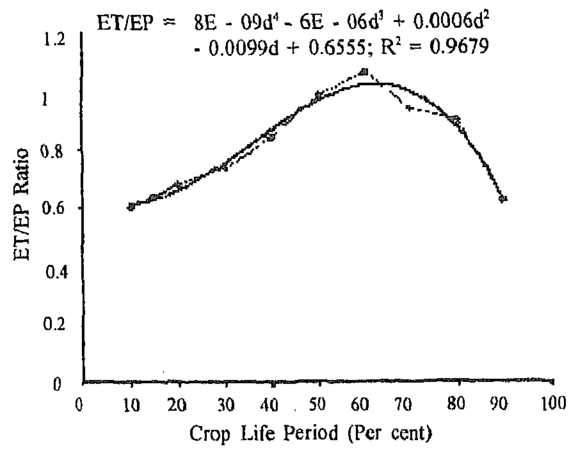

Fig. 2. Generalised growth and ET/EP relationship

following equation was found to be best in describing this relationship.

$$ET/EP = 8E\text{-}09d^4 - 6E\text{-}06d^3 + 0.0006d^2 - 0.0099d + 0.6555$$

Where 'd' is the crop life period in terms of per cent of total life period. From the values of EP and using the above equation it is possible to estimate ET in any time of the crop growth.

Water use efficiency

The efficiency of a field crop to use available water is governed largely by its variety, soil type and environment conditions. Naturally it varies from location to location but even at the same location for a specific variety, the efficiency changes with changes in weather conditions.

Nevertheless, an attempt has been made in this paper to compute water use efficiency as given below:

Water use efficiency (WUE) =

$$\frac{\text{Yield in kg / ha}}{\text{Consumptive water use (mm)}}$$

The WUE is given for each of the stations in Table 1.

It is obvious from the table that for the variety of Parbhani, the WUE is the least and hardly exceed 3 kg ha^{-1} mm^{-1}. In other words, this location does not seem to be suitable for growing soybean crop. On the other hand, the crop records consistent high WUE exceeding 5 kg/ha/mm at Rahuri. Banswara is perhaps another location where the crop has a high potential for the cultivation of soyabean.

Rainfall and yield

In the present study a attempt was made to determine if the seed yield is in any way, dependent on the rainfall during the crop season. The linear relationship computed between the two, was found to be rather weak. As such, a power regression in the following form was attempted

$$Y = AR^B$$

Where Y is yield (q/ha), R seasonal rainfall (mm) and A and B are the constants.

This model did not give significant correlation. However, when the rainfall was split into different phases, a very large correlation (r = 0.85) was found between yield and rainfall (R) during the vegetative phase. This led to the following equation:

$$Y = [0.79\ R^{0.79} \times Y_p] / 100 \qquad (r = 0.85)$$

Where, Y_p is the potential yield (q/ha)

It is thus obvious that, rainfall during vegetative phase plays a crutial role in the crop development and yield. According to Al-Hazim *et al.* (1996), the soybean crop needs about 50 cm of rainfall to attain its full potential.

Crop duration and yield

Total duration of crop growth as well as duration during various phases were also correlated with yield. The correlations obtained are discussed below phase were :

(i) Vegetative phase : The phase duration, i.e. the period from sowing to commencement of flowering, varied from 32 days at Parbhani to 49 days at Rahuri. Seed yield and vegetative phase duration were found to be significantly correlated. The following linear relation was observed between seed yield Y (q/ha) and the duration of vegetative phase, D_v (days).

$$Y = 1.223\ D_v - 34.5 \qquad (r = 0.81)$$

(ii) Flowering phase : The mean duration of the phase was about 2 weeks though it varied from 10 to 27 days. Higher seed yields were obtained when the flowering phase duration was about 16 days, the mean duration of this phase obtained in the study. It is observed that, the seed yield is significantly correlated with the flowering phase duration (D_F). On either side of the mean value (i.e. 16 days), the following relations could be established :

a) $Y = 4.27\ D_F - 40.04$, $(r = 0.91)$

for shorter duration of the phase i.e. < 16 days.

b) $Y = 55.93 - 1.92\ D_F$ $(r = -0.88)$

for longer duration of the phase i.e. > 16 days.

It is thus clear that a shorter duration of flowering gives higher yield whereas a longer duration perhaps lead to drop in flowering rate and consequent reduction in the yield.

(iii) Maturity phase : This phase includes the pod formation, seed filling and seed hardening. The phase duration varied from 35 days at Parbhani to 58 days at Banswara. No significant correlation was observed between the phase duration and the seed yield.

(iv) Crop life : The crop life duration D varied from 87 days at Parbhani (var : Monetta) to 120 days at Banswara (var : Gaurav). The seed yield 'Y' varied from 5.51 q/ha at Parbhani to as high as 24.31 q/ha at Banswara. Correlation between yield and crop growth duration D, though not high as obtained above, was nevertheless significant and the following regression equation was obtained :

$$Y = 1.16\ D - 100.49 \qquad (r = 0.63)$$

Evapotranspiration and yield

The seed yield was also correlated with ET during the crop life period as well as phase-wise cumulative ET values. It was observed that, a significant correlation exists between them for vegetative phase only (r = 0.82). Correlation of Y with total ET as well as ET in remaining phases, was found very poor and hence, has not been discussed.

Conclusion

The following conclusions can be drawn from the study:

(i) The maximum evapotranspiration for soybean was noticed during flowering phase followed by the vegetative phase.

(ii) ET/EP ratio generally rises till the flowering phase and thereafter declines gradually.

(iii) A significant linear relationship exists between seed yield and rainfall during the vegetative phase.

(iv) The yield is also found to be significantly correlated with the crop growth duration in vegetative and flowering phase.

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